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ABSTRACT

Three-month-old infants learned to activate a crib mobile by means of operant footkicks. Retention of the conditioned response was assessed in the presence of the nonmoving mobile. Although forgetting is typically complete after an 8-day retention interval, infants who received a reactivation treatment, a brief exposure to the reinforcer 24 hours prior to testing, showed no forgetting after retention intervals of either 2 or 4 weeks. Further, the forgetting function following reactivation did not differ from the original forgetting function. These experiments demonstrate (1) that "reactivation" or "reinstatement" is an effective mechanism by which early experiences can be maintained over lengthy intervals; and (2) that memory deficits in infants are best viewed as retrieval deficits. (Author)

Rovee-Collier, 1.

Reactivation of Infant Memory

The pervasive influences of early experiences on later behavior have been extensively documented (1), as have early memory deficits or "infantile amnesia" (2). Considered jointly, these phenomena pose a major paradox for students of development: ~~How~~ can the effects of early experiences persist into adolescence and adulthood if they are forgotten during infancy and early childhood? Campbell and Jaynes (3) proposed a resolution to this paradox in terms of <u>reinstatement</u>, a mechanism which serves to maintain a memory which would otherwise be forgotten through occasional reencounters with the original training conditions over the period of development. Any given reencounter, however, would be insufficient to promote new learning in organisms who lacked the early experience. Spear (4) attributed the efficacy of reinstatement procedures to improved retrieval produced by the reactivation of a sufficient number or kind of existing but otherwise inaccessible attributes of the target memory. Reexposure to stimuli from the original training context which had been stored as attributes of that memory was hypothesized to prime or arouse other attributes which represented the original experience, increasing their accessibility and, thus, the probability of their retrieval.

"Reinstatement" or "reactivation" has been demonstrated in young and adult rats (3, 5, 6, 7) and in grade-school children (8). We now report that a reactivation treatment can alleviate forgetting in 3-month-old infants after a retention interval as long as 4 weeks and that the forgetting function following reactivation does not differ from the function following original training.

Our procedures were modeled after those of animal memory studies in which the experimenter trains a specific response in a distinctive context and later returns the subject to that context to see if the response is still produced (5, 9). Because the retrieval cues are contextual, and response production is assessed prior to the reintroduction of

reinforcement, the procedure is analogous to a test of cued recall (4, 10). In our studies, footkicks of 3-month-olds were reinforced by movement of an overhead crib mobile. The infant controlled both the intensity and the frequency of the mobile movement by means of a ribbon connected from his ankle (Fig. 1a) to the hook from which the mobile hung. This procedure, "mobile conjugate reinforcement" (11), produces rapid acquisition and high, stable response rates not attributable to behavioral arousal (12). During nonreinforcement phases (baseline, retention tests, extinction), the mobile remained in view but was hung from a second mobile stand with no ribbon attachment and could not be activated by kicks. Infants received 3 procedurally identical sessions. The first two were training sessions, spaced by 24 h; the third followed a lengthy retention interval. Each session consisted of a 9-min reinforcement phase preceded and followed by a 3-min nonreinforcement period. In Session 1, the initial nonreinforcement period defined baseline; in Sessions 2 and 3, it was a long-term retention test of the effects of prior training. Total footkicks during this test (B) were expressed as a fraction of the infant's total kicks during the nonreinforcement phase at the conclusion of the preceding session (A), which was an immediate retention test. The ratio B/A indexed the extent of an infant's forgetting from one session to the next. Ratios of $\geq$ 1.00 indicated no forgetting and < 1.00, fractional loss (13). A reactivation treatment (6) was administered 24 h prior to Session 3. It consisted of a 3-min exposure to the reinforcer (mobile movement) in a context identical to that of Session 2 except that (i) the ribbon was not connected to the ankle but draped over the side of the crib, where it was drawn and released by the experimenter at a rate which corresponded to each infant's mean response rate during the final 3 min of acquisition in Session 2; and (ii) the infant was in a reclining seat (Fig. 1b) which minimized footkicks and altered the topography of those which did occur (14). These changes,

as well as the brevity of the reminder, precluded the opportunity for new learning or practice during a reactivation treatment. Footkicks were recorded by the experimenter and, independently, by a second observer present for at least 40% of the sessions and naive with respect to group assignment and session number. Pearson product moment reliability coefficients were $\geq$ 0.95 for all studies reported here.

In Study 1, retention of conditioned footkicks was assessed 2 weeks after training. Infants ($\bar{X}$ age = 88.4 days, S.E. = 3.3) were tested in 3 groups of 6 each: (i) a reactivation group received a 3-min reminder 13 days following Session 2 (24 h before Session 3); (ii) a no-reactivation group received training but no reactivation treatment prior to Session 3; and (iii) a familiarization/reactivation control group received a procedure identical to that of the reactivation group except that infants in this group were removed from their cribs during the reinforcement phases of Sessions 1 and 2, thus had no training prior to Session 3. This group showed no change in response rate either within or across sessions (all t's < 1). Thus infants of this age do not simply become more active over the 2-week interval or more active as a result of elicited familiarity reactions, or the reactivation treatment per se. The initial acquisition curve of this group in Session 3 was indistinguishable from the Session-1 learning curves of the other groups (Fig. 2a). An analysis of variance with repeated measures over Sessions and Blocks confirmed that the reactivation and no-reactivation groups did not differ during training. A 2 x 2 analysis of variance over retention ratios yielded a significant Group x Sessions interaction: although 24-h retention ratios did not differ, the 2-week retention ratio of the reactivation group significantly exceeded that of the no-reactivation group (P < .01), whose ratio reflected a return to operant level (Fig. 2b, 14-day retention interval). Moreover, the retention ratio of the reactivation group was as high as it had been in the 24-h measure. Thus

both prior training and a reminder are prerequisite for reactivation.

In Study 2, we repeated the preceding procedure with 18 additional infants ($\bar{X}$ age = 76.9 days, S.E. = 2.0) but doubled the length of the retention interval. The reactivation group (N=9) received a reminder 27 days following training, and retention was assessed 28 days following training. A significant Group x Sessions interaction ($\underline{P}<.03$) again confirmed the superior retention of the reactivation group in Session 3 relative to that of the no-reactivation group (N=9) which had received no reminder during the retention interval (Fig. 2b, 28-day retention interval). As before, the groups had not differed during training (Fig. 2a) or in 24-h retention. The 28-day ratio of the reactivation group was equivalent to their 24-h performance, but that of the no-reactivation group was equivalent to operant level. The retention of the reactivation group is particularly remarkable in view of the relatively young age of the infants during training and the relatively large portion of their lives that 4 weeks constitutes.

In Study 3, we determined the course of forgetting following a reactivation treatment. Twenty infants ($\bar{X}$ age = 90.0 days, S.E. = 1.3) received a reactivation treatment 13 days after training as described in Study 1; however, Session 3 now occurred either 3, 6, 9, or 15 days (N=5 per group) after the reminder. This corresponded to 16, 19, 22, or 28 days, respectively, following original training. The Session-3 retention ratios, along with those of the 6 infants tested 1 day after a reactivation treatment (14 days after training) in Study 1, were compared with retention ratios which we had previously obtained from 69 infants in a number of different experiments (15) involving the same procedure as that used with the no-reactivation groups of this report. These infants contributed data points describing the original forgetting function 1, 2, 3, 4, 5, 7, 8, and 14 days following training. None of these points (Fig. 2b) was based on data from fewer than 5 infants.

The no-reactivation group of Study 2 contributed an anchor point for performance 28 days following training against which the reactivation group tested 15 days after the reminder (28 days after training) could also be compared. A composite showing retention ratios of all groups following 2 days of training only ("original memory" function) or following training plus a reactivation treatment ("priming") given either 13 (Studies 1, 3) or 27 (Study 2) days after training ("reactivated memory" function) is shown in Fig. 2b. Regression analyses over the two forgetting functions indicated that, in each instance, retention was a linear decreasing function of time since either training ($P<.005$) or priming ($P<.005$). Although the linear model provided a relatively poor fit in each instance, the parameter estimates for the two functions did not differ (t's < 1): Values of the intercept and slope of the original forgetting function were 1.07 (S.E.=0.12) and -0.05 (S.E.=0.02), respectively; those of the reactivation forgetting function were 1.17 (S.E.= 0.15) and -0.06 (S.E.=0.18), respectively. In addition, a one-way analysis of variance over all data points except that of the Study-2 reactivation group indicated that ratios differed reliably as a function of retention interval ($P<.025$) and provided the error term for individual comparisons between means (Duncan's multiple range test). The latter indicated that the apparent increase in retention performance following priming (retention intervals of 2 and 16 days: Fig. 2b) was reliable; also, ratios after retention intervals of 8 and 19 days did not differ from ratios of nonreactivated groups after intervals of 14 and 28 days. Thus forgetting of a reactivated memory follows the same temporal course as forgetting of the original experience.

Our findings confirm Campbell and Jaynes' (3) original proposition that reinstatement is a potent mechanism through which experiences of early infancy can continue to influence behavior. If an infant reencounters aspects of a prior training context, or the context of an earlier

experience, this can prime or recycle the remaining memory attributes and enhance access to them, as evidenced by enhanced retention during cued recall tests administered as long as a month later. Moreover, we have shown that a reencounter with the original context can maintain access to the target memory with the same efficacy as original training. Finally, our findings implicate reinstatement as the mechanism which facilitates, during the infancy period, the acquisition of the vast amount of learning which characterizes that period of development. More generally, these findings support a distinction between availability and accessibility of information in memory and imply that failures to observe retention in infants should be discussed in terms of retrieval failures rather than memory deficits (4, 10). We think that procedures which improve accessibility to important retrieval cues will radically alter current views of infant memory (16) and that conditioning procedures, used with infants, offer a promising means by which to bridge the gap between human and animal memory research.

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13. Because operant levels typically double or triple during acquisition, retention ratios of .3-.4 usually indicate performance at operant level. We have also established that a 3-min period of nonreinforcement at the conclusion of a training session is insufficient to result in extinction after only 1-2 sessions in infants trained between 11 and 13 weeks of age.
14. Response counts/min indicate a range of 0-2 kicks/min infants be-

tween 13 and 16 weeks of age during the reactivation treatment; operant levels at this age are typically 8-11 kicks/min. Infants in the infant seat rarely exhibit vertical leg thrusts characteristic of conditioned responding; rather, their movements are most frequently horizontal and appear to be postural adjustments or, simply, "squirming" movements.

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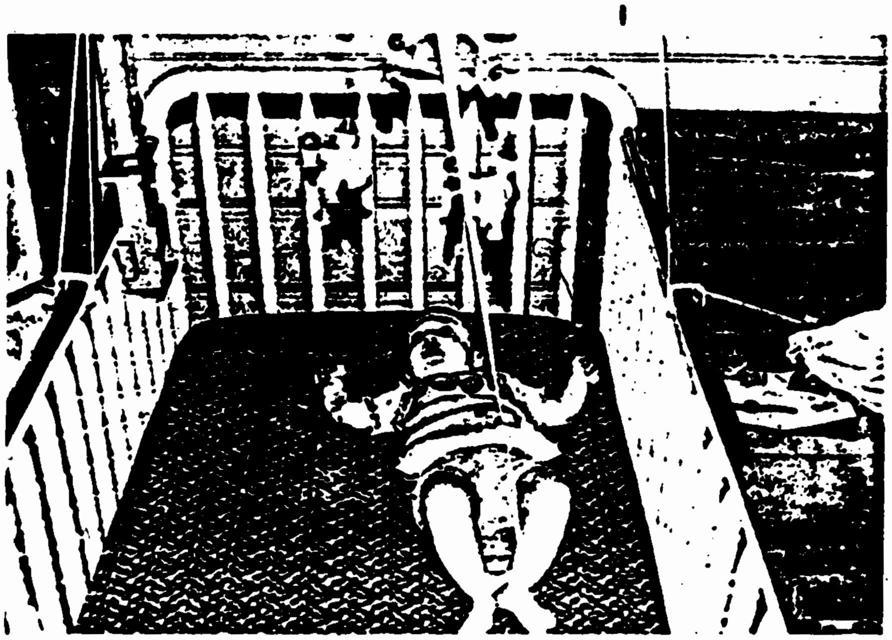
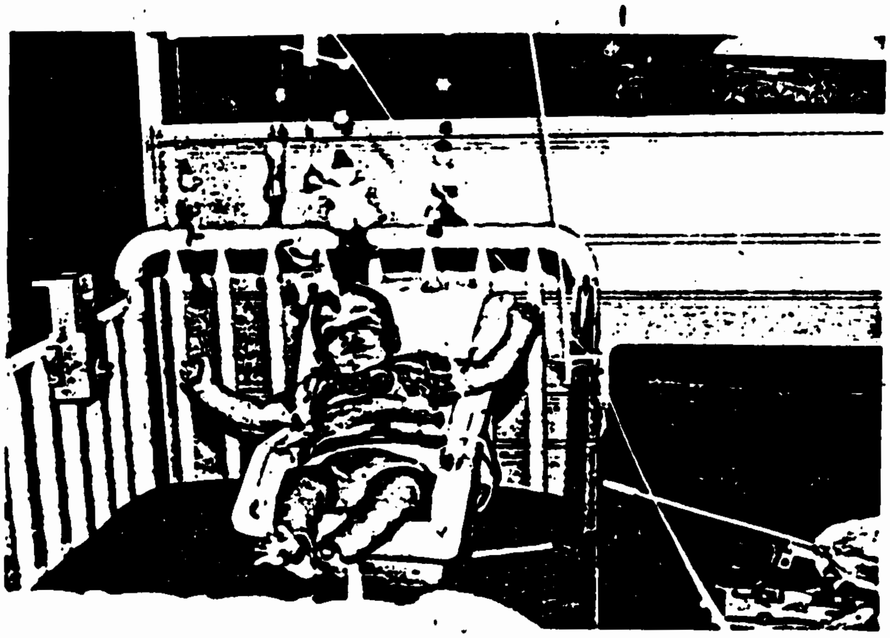
17. Study 1 of this research formed a portion of a dissertation submitted by M.W.S. to Rutgers University in partial fulfillment of the requirements for the Ph.D. Supported by NIMH grant MH 32307 to CKRC.

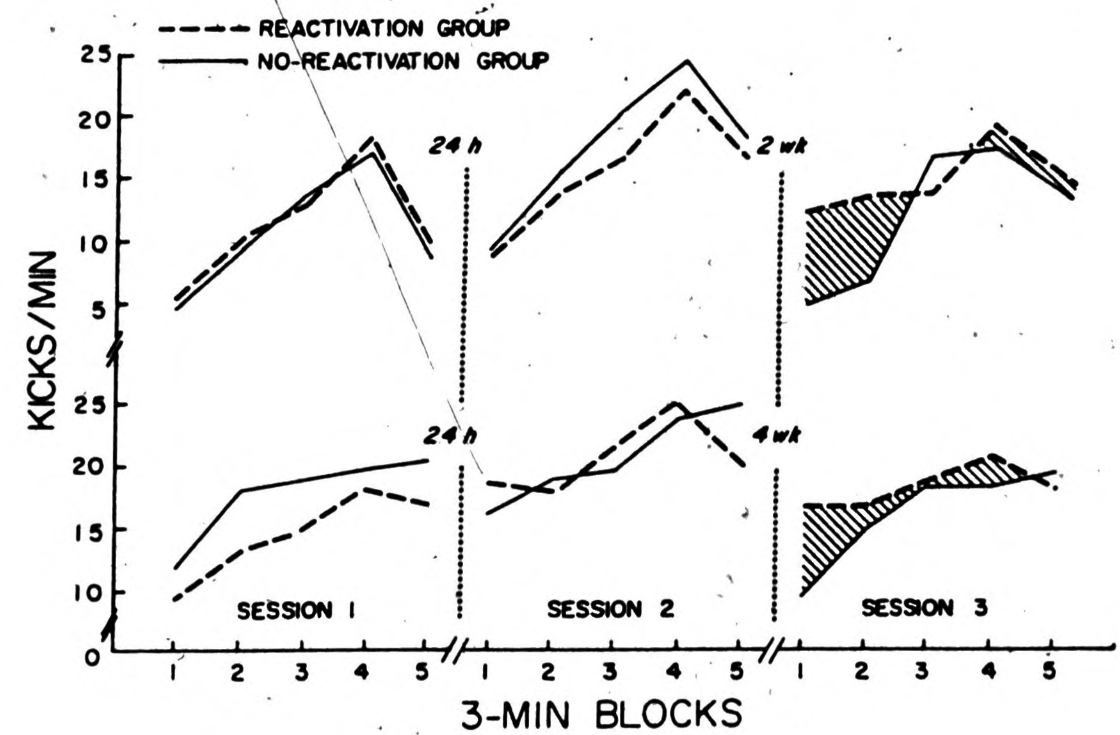
Figure Captions

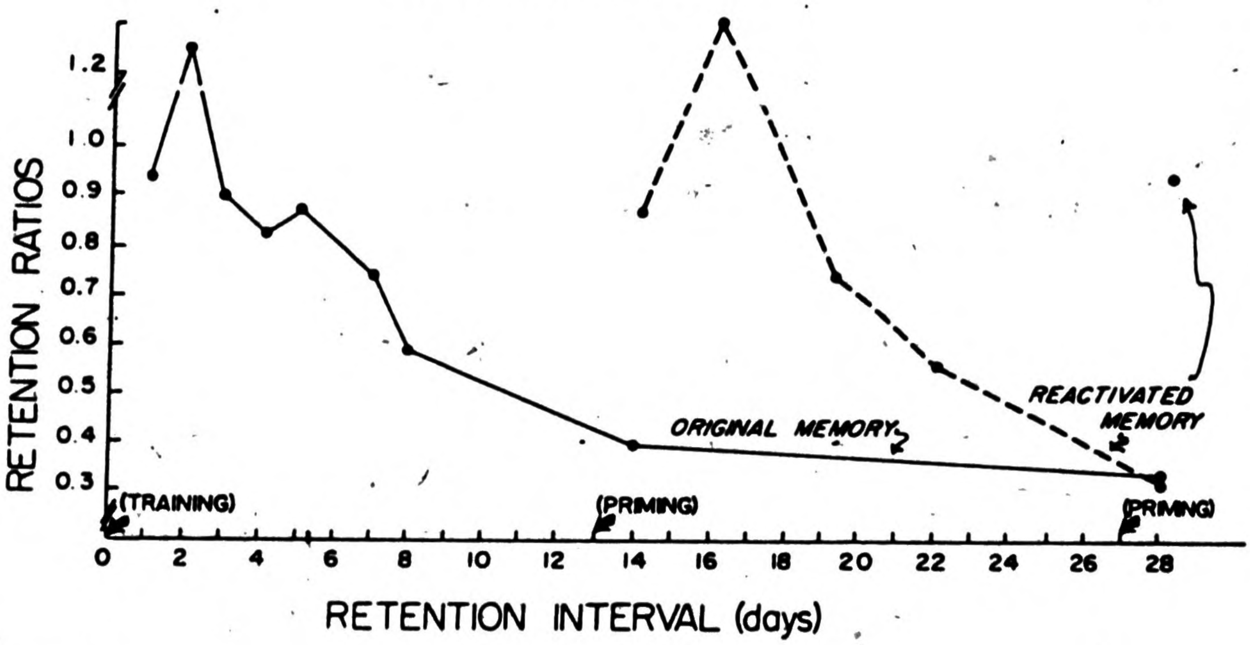
Fig. 1. (a, top) View of the infant during a reinforcement phase with the ankle ribbon attached to the same suspension bar as that from which the mobile is hanging. The "empty" mobile stand, which will hold the mobile during periods of nonreinforcement, is clamped to the crib rail at the left. (b, bottom) View of the infant during a reactivation treatment. The mobile and ribbon are attached to the same suspension hook, but the ribbon is drawn and released by the experimenter (not shown), concealed from the infant's view at the side of the crib. The infant will be exposed to the reinforcer (the moving mobile) for only 3 min. 24 h prior to retention testing.

Fig. 2. (a, top) Mean kicks/min during training (Sessions 1, 2) and a temporally distant (2 or 4 weeks) Session 3. Blocks 1 and 5 in every session are nonreinforcement phases. Performance during long-term retention tests (Block 1, Sessions 2 or 3) is expressed as a fraction of the infant's performance during immediate retention tests (Block 5, Sessions 1 or 2, respectively). The reactivation group received a reminder of the reinforcer 24 h prior to the 2- or 4-week session; the facilitating "priming" effect of the reactivation treatment is indicated by the hatched area, Session 3. (b, bottom) Retention ratios following two days of training (solid line) or two days of training and a reactivation treatment (broken line); the arrow indicates that the priming occurred 13 days after training for all points connected by broken lines, or 27 days after training for the single data point at the 28-day retention interval. Each data point represents at least 5 infants.






REACTIVATION GROUP
NO-REACTIVATION GROUP
KICKS/MIN
24 h
2 wk
4 wk
SESSION 1
SESSION 2
SESSION 3
3-MIN BLOCKS


RETENTION RATIOS
ORIGINAL MEMORY
REACTIVATED MEMORY
(TRAINING)
(PRIMING)
(PRIMING)
RETENTION INTERVAL (days)